

Search for Extra Dimensions at Hadron Colliders

International Europhysics Conference on High Energy Physics

Aachen, July 2003

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Outline

- Extra Dimensions phenomenology
- Results from experiments at TeVatron
- Future at LHC (See also L. Vacavant's talk)
- Conclusions

Abstract # 419, 488, 596, 609

Extra Dimensions

– Standard Model works surprisingly well, but:

- * Why is $M_{\text{Pl}} \sim 10^{16} \times M_{\text{EW}}$?
- * Gravity ?
- * Dark matter ?
- * . . .

⇒ Does gravity propagate in more than four dimensions ?

- * If n compact extra dimensions with radius $\sim R$
- $R \sim \frac{1}{M_S} (M_{\text{Pl}}/M_S)^{2/n}$
- * Take $(4 + n)$ dimensional Planck scale $M_S = M_{\text{Pl}}^{(4+n)} \sim M_{\text{EW}}$

⇒ For $n \geq 3$, $R \lesssim 1 \text{ nm}$: not excluded by gravitational experiments !

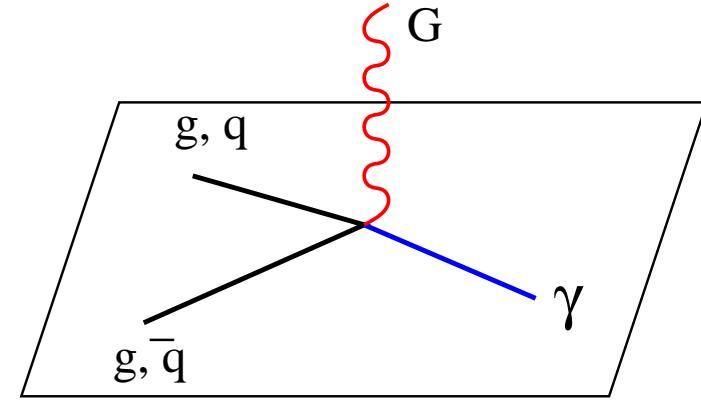
Extra Dimensions Phenomenology

- Arkani-Hamed, Dimopoulos, Dvali (ADD): “large” Extra Dimensions
 - * At high energy, many graviton excitations
 - ⇒ Increase of collision cross sections
 - Randall, Sundrum (RS): one “small” Extra Dimension, “warped” by exponential factor $e^{-2kr_c\phi}$
 - * At high energy, single graviton excitations
 - ⇒ Spin-2 resonance production in collisions
- ⇒ Look for signs of Extra Dimensions in collider experiments !

Experimental Signatures

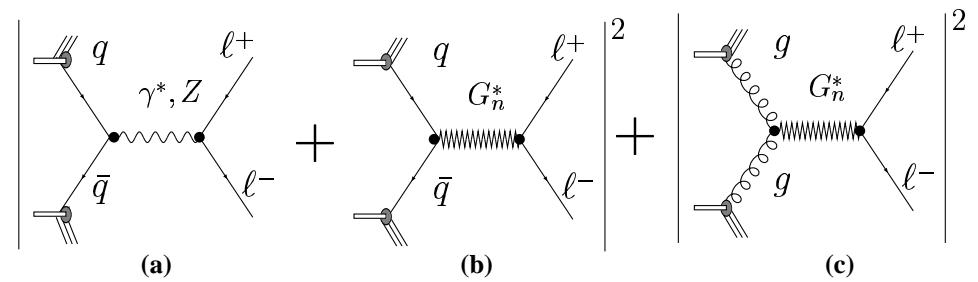
Graviton emission:

- ⇒ Anomalous production of
- * Jets + \cancel{E}_T
 - * $\gamma + \cancel{E}_T$



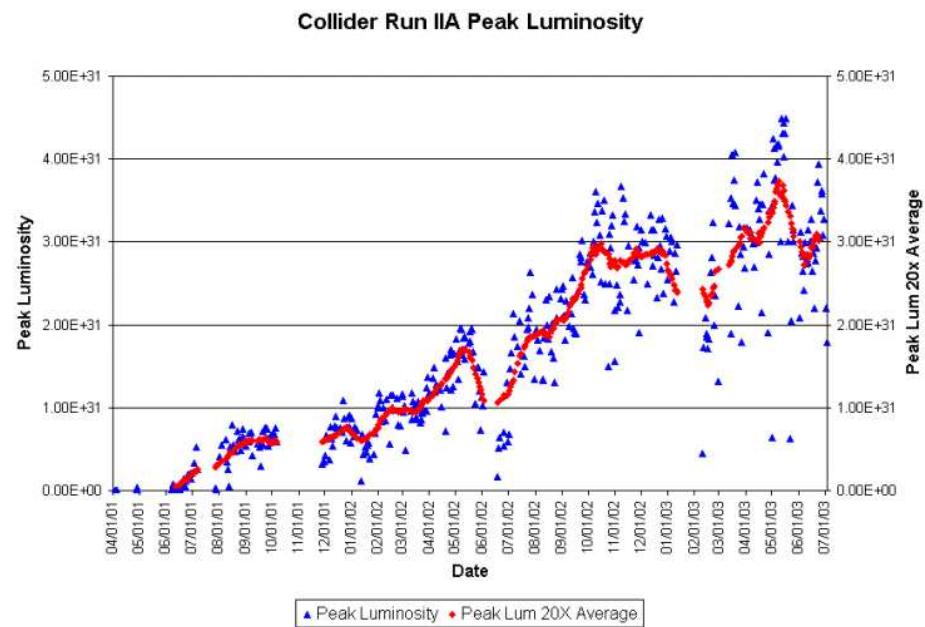
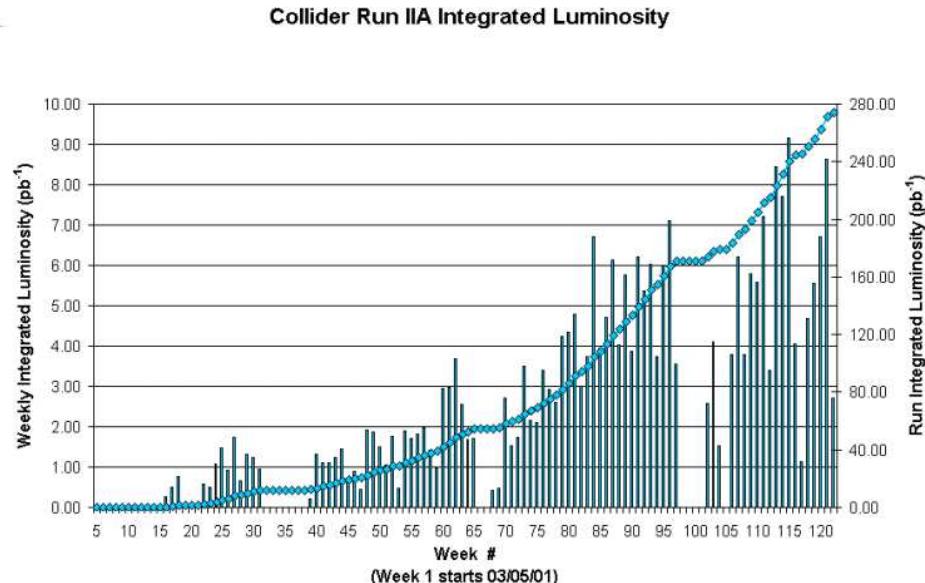
Graviton exchange:

- ⇒ Anomalous production of
- * Di-leptons
 - * Di- γ 's



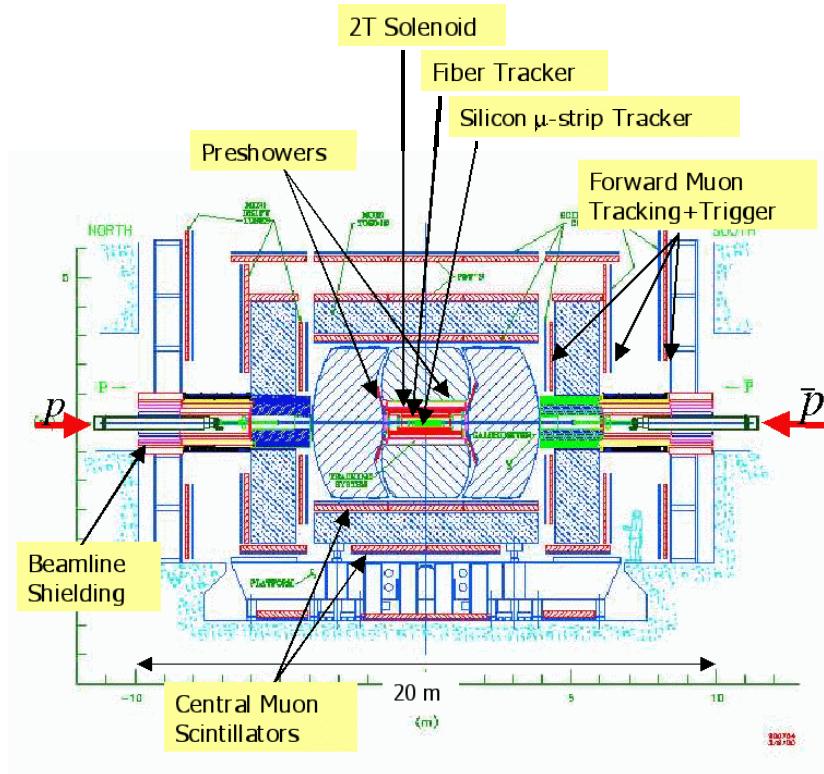
TeVatron

- $p\bar{p}$ Collider
 - * $\sqrt{s} = 1.8 \text{ TeV}$ (Run I)
 - * $\sqrt{s} = 1.96 \text{ TeV}$ (Run II)
- Higher luminosity and cross sections in Run II



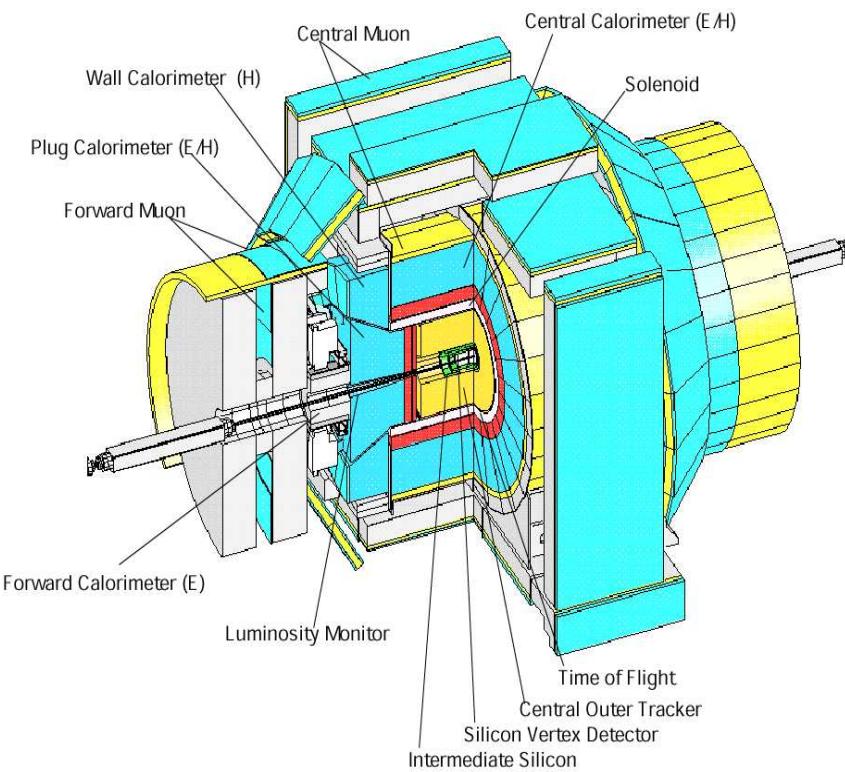
Run II Detectors

Major upgrades from Run I



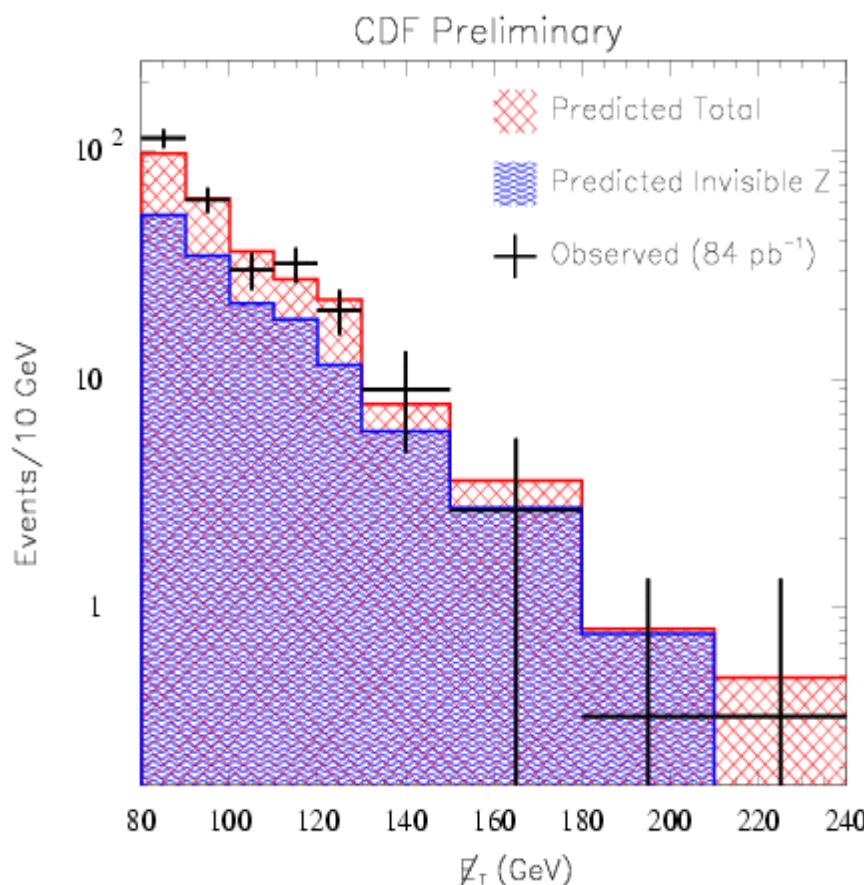
DØ

CDF



ADD Graviton Emission: Jets + \cancel{E}_T (CDF, Run I)

- Relatively large cross section
- Background from Z ($\rightarrow \nu\bar{\nu}$) + jets production



Consistent with no signal

\Rightarrow Lower limits on M_S (in GeV):

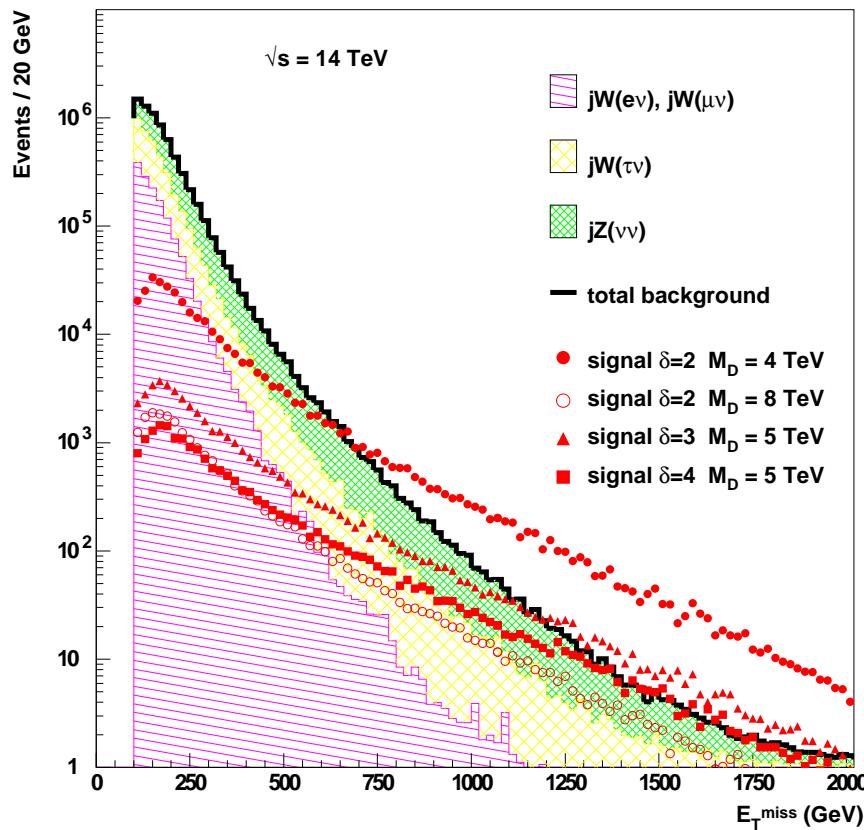
n	2	4	6
	1000	770	710

Likewise for $\gamma + \cancel{E}_T$:

n	4	6	8
	549	581	602

ADD Graviton Emission: Jets + E_T (ATLAS)

- $\sqrt{s} = 14 \text{ TeV}, 100 \text{ fb}^{-1}$
- More background sources



Discovery potential !

- $E_T^{\text{jet}} > 1 \text{ TeV}$
 - ≥ 100 signal events
 - Significance > 5
- ⇒ Mass scale M_D reach (in TeV):

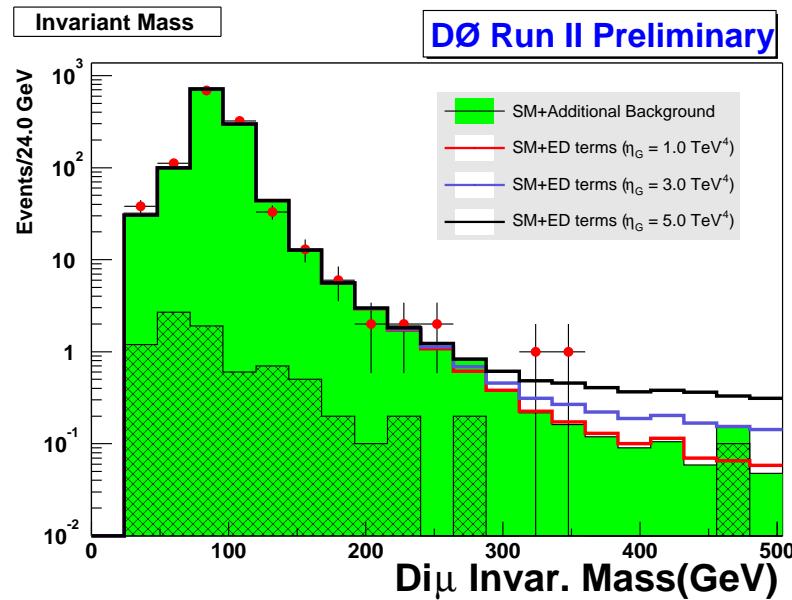
n	2	3	4
	9.1	7.0	6.0

ADD Graviton Exchange: Di- μ , Di- γ

$$\sigma = \sigma_{\text{SM}} + \sigma_{\text{int}} \eta_G + \sigma_{\text{KK}} \eta_G^2, \quad \eta_G = \mathcal{F}/M_S^4$$

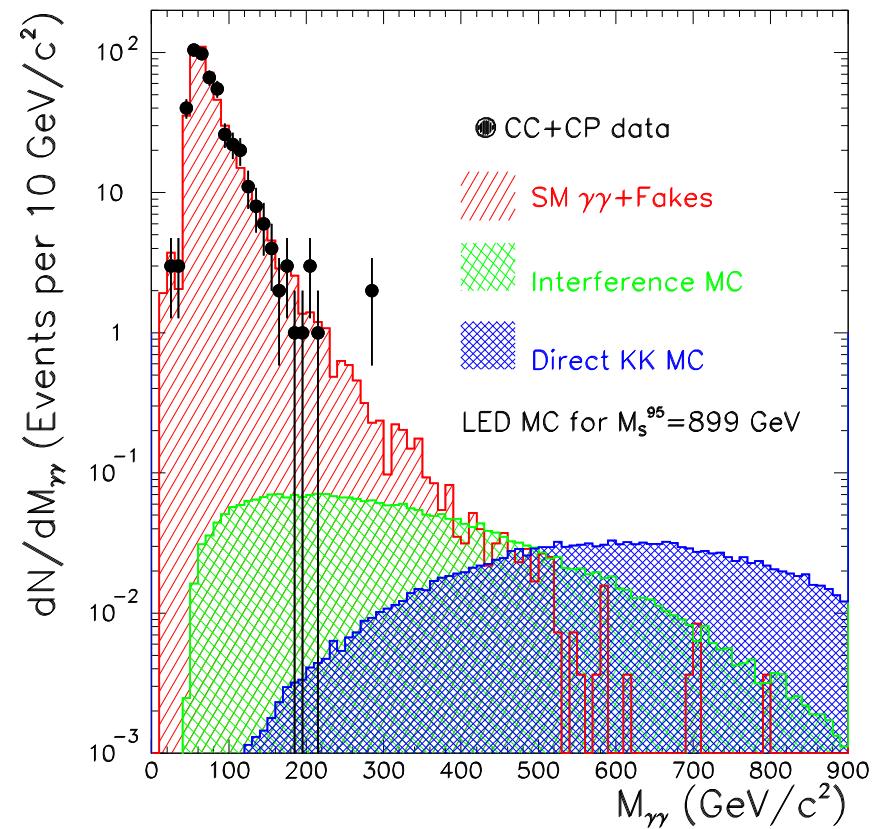
DØ Run II, Di- μ channel, 30 pb $^{-1}$

- $p_T > 15$ GeV, $M_{\mu\mu} > 40$ GeV
- Background:
 - * Drell-Yann (MC)
 - * Heavy quark decay (data)



CDF Run I, 87-100 pb $^{-1}$

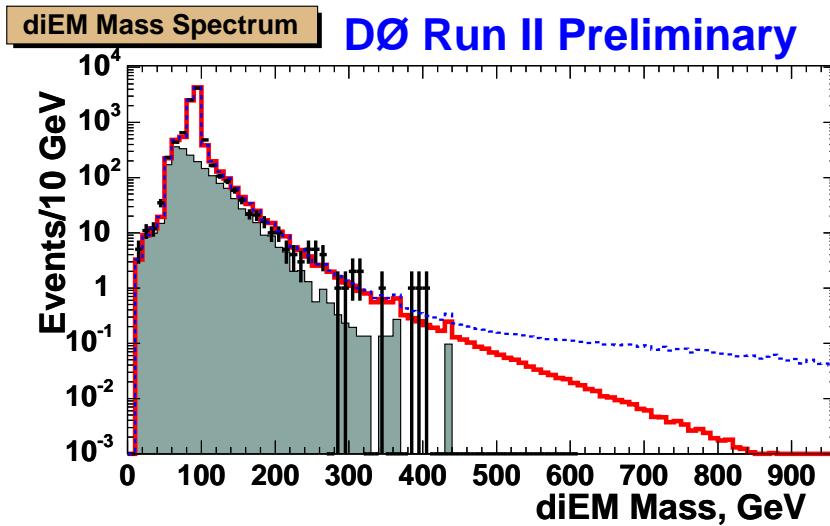
CDF Preliminary



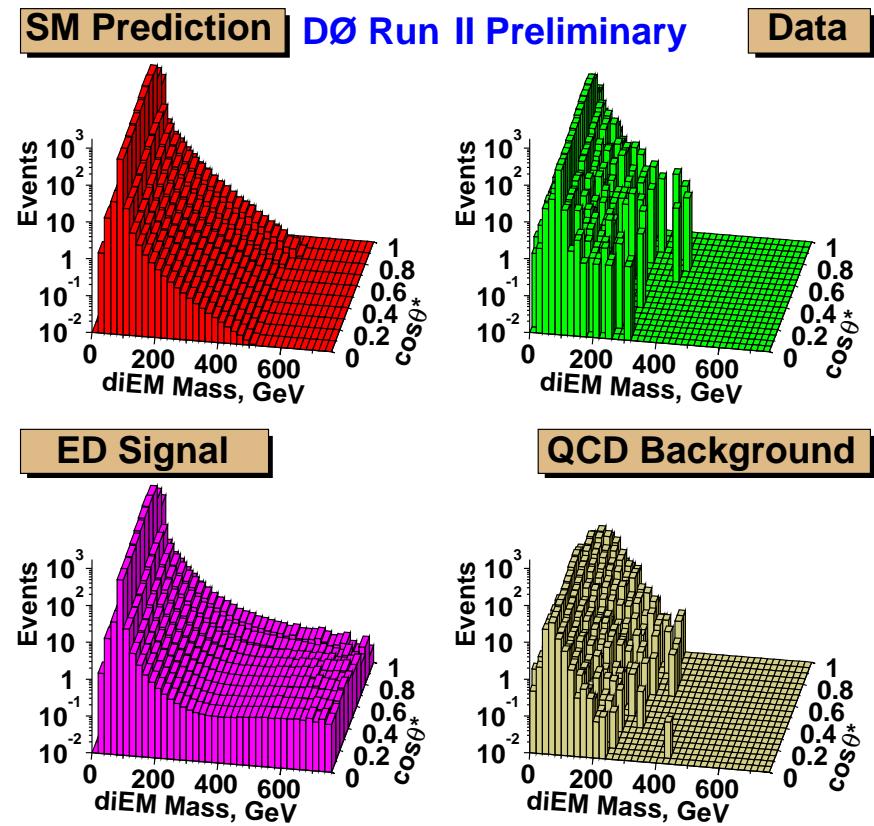
ADD Graviton Exchange: Di-EM

DØ Run II, 120 pb⁻¹

- $E_T > 25$ GeV
- Background:
 - * Drell-Yan, di- γ (MC)
 - * fake EM from QCD (data)



$$\frac{d^2\sigma}{dM d \cos \theta^*} = f_{\text{SM}} + f_{\text{int}} \eta_G + f_{\text{KK}} \eta_G^2$$



ADD Graviton Exchange: Results

No signal observed \Rightarrow Fit to SM + graviton expectation, extract limits

DØ Run II

Lower limits on M_S (in TeV):

	GRW	HLZ $n = 2$	HLZ $n = 7$	Hewett $\lambda = +1$
di-EM	1.28	1.42	1.01	1.14
di- μ	0.79	0.68	0.63	0.71

CDF Run I

Lower limits on M_S (in GeV):

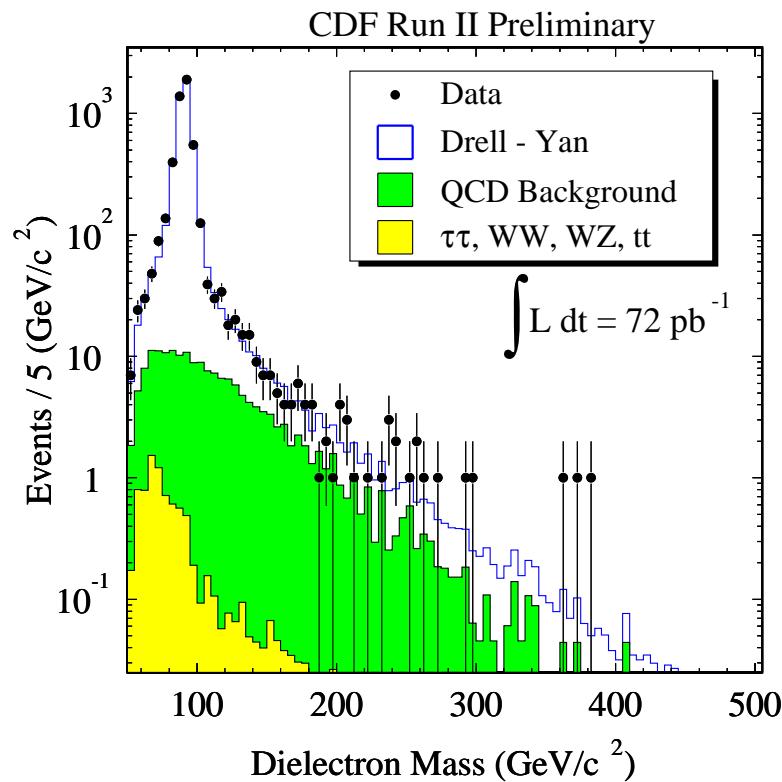
	Hewett	
	$\lambda = -1$	$\lambda = +1$
ee	826	808
$\gamma\gamma$	899	797
di-EM	939	853

- Di-EM: $\eta_G = 0.0 \pm 0.15 \text{ TeV}^{-4}$
- Di- μ : $\eta_G = 0.02 \pm 1.35 \text{ TeV}^{-4}$

RS Resonance Production (CDF, Run II)

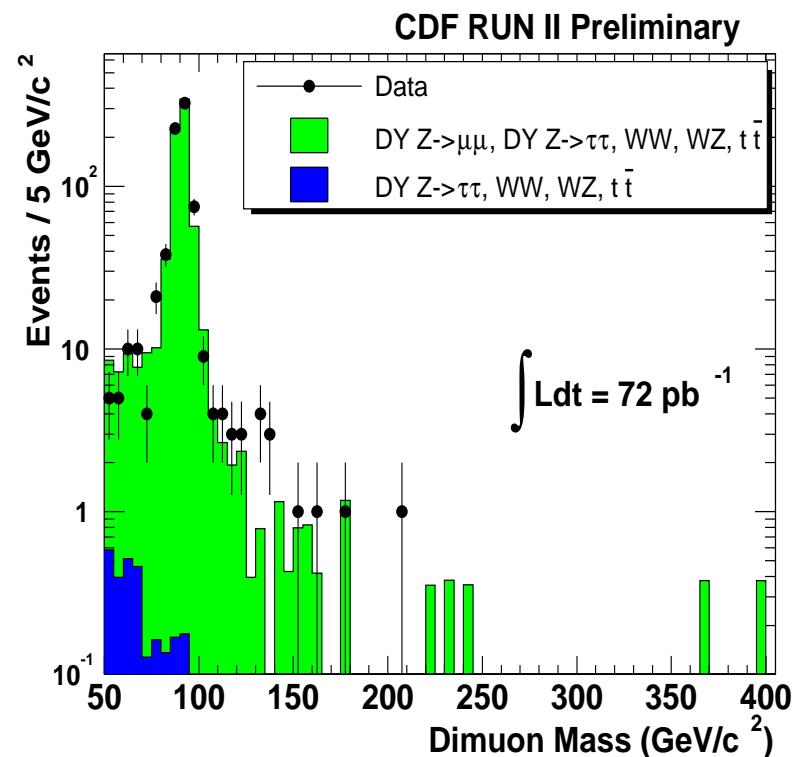
Di-electron channel, 72 pb^{-1}

- $- E_T > 25 \text{ GeV}, |\vec{E}_T|/\sqrt{\sum E_T} < 2.5$



Di- μ channel, 72 pb^{-1}

- $- p_T > 20 \text{ GeV}$, Cosmic rejection



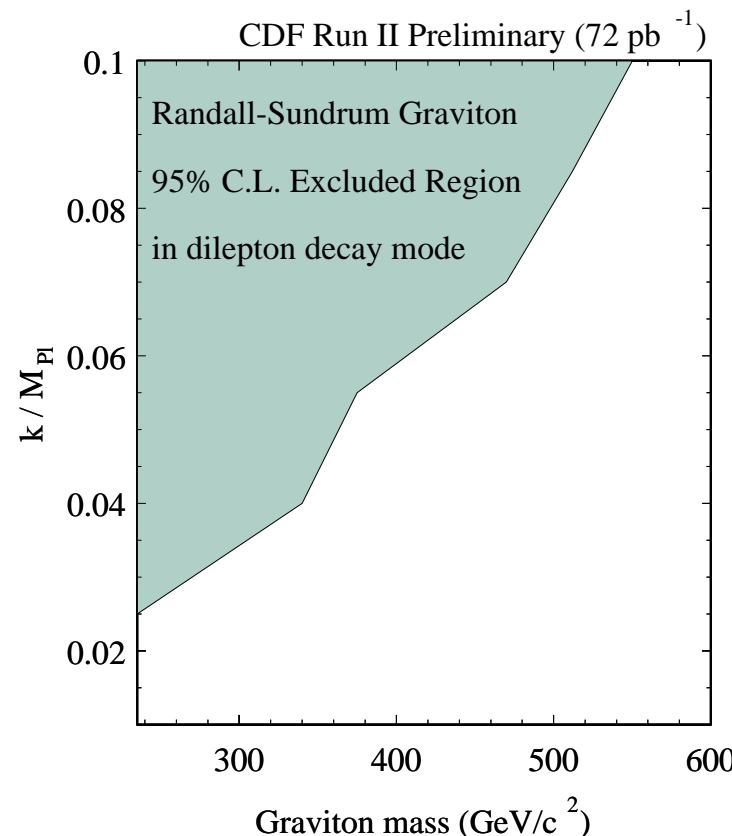
Consistent with no signal \Rightarrow RS graviton mass limits (in GeV):

channel	ee	$\mu\mu$	combined
	535	370	550

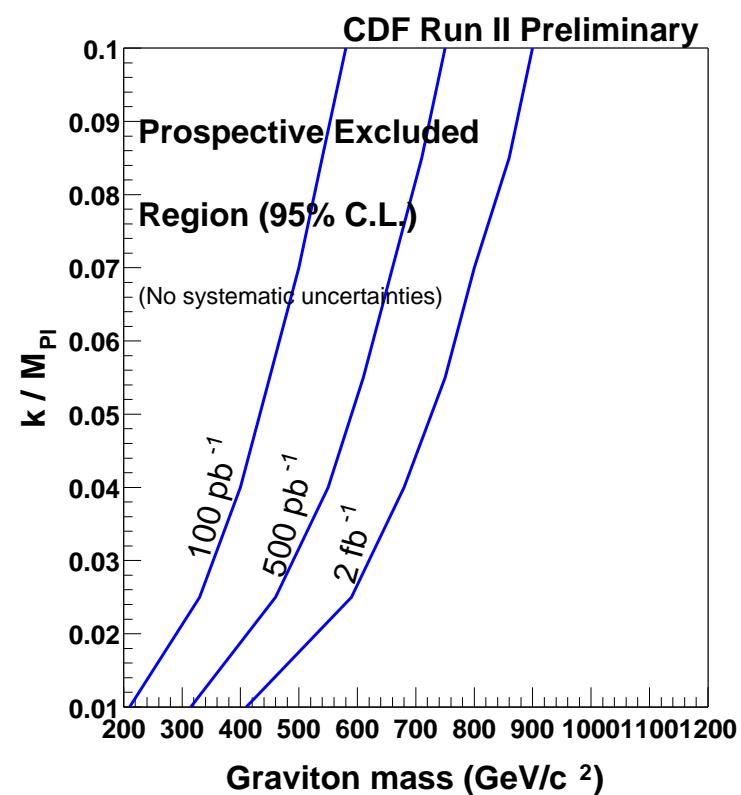
RS Resonance Production (CDF, Run II)

RS graviton mass vs coupling limits

Current:



Expected in Run II (di-electron):

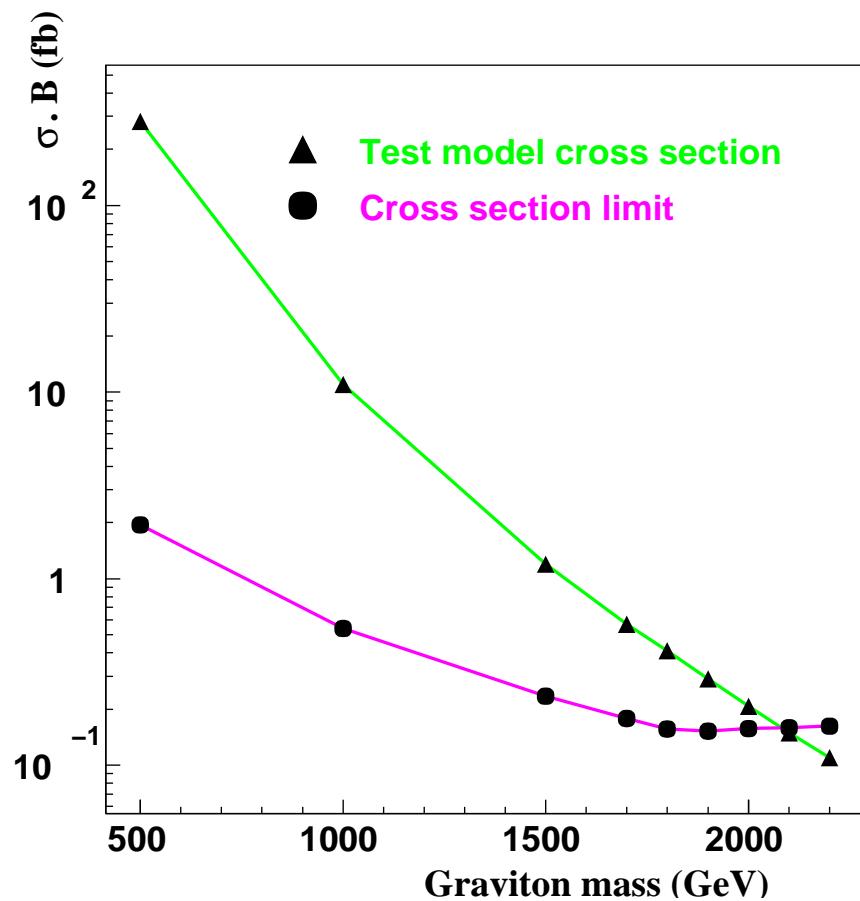


See also Z' search (M.P. Giordani's talk)

RS Resonance Production (ATLAS)

– $\sqrt{s} = 14 \text{ TeV}, 100 \text{ fb}^{-1}$

⇒ Cross section limit



⇒ Max. mass = 2080 GeV

Conclusion

- Extra Dimensions as a solution to hierarchy (and others)
- No Extra Dimensions found, yet \Rightarrow model limits
- More to expect from TeVatron experiments
- Even more from LHC experiments